tes
nt of

Forest Service

Technology &
Development
Program

2300—Recreation
July 1995
9523 1803—SDTDC

COMPOSTING TOILET SYSTEMS, PLANNING, DESIGN, & MAINTENANCE

COMPOSTING TOILET SYSTEMS, PLANNING, DESIGN, & MAINTENANCE

Brenda L. Land
Sanitary Engineer

San Dimas Technology & Development Center
San Dimas, California 91773

July 1995

TABLE OF CONTENTS

FIGURE LIST

INTRODUCTION

The objective of this publication is to provide:

- Recreational managers information necessary to evaluate compost toilets as a waste management option during the planning stage

- Engineers and Landscape Architects basic information necessary for a functional compost toilet building design

Figure 1. Bruce Peninsula National Park, Tobermory, Ontario, Canada. Accessible composting toilet building over a daylight basement, designed by Sunergy Systems LTD. The glazed roof area includes a skylight for each toilet room, and solar heat collector for digester intake air. The photovoltaic electrical panels are mounted in a tree to get maximum sun light.

- Contracting Officers Representatives (COR's) information necessary to compare different brands and evaluate submittals

- Health and Safety officers, and supervisors information necessary to conduct a job hazard analysis and training program and

- Recreational technicians information on the maintenance needs of composting toilets.

Planning, designing, or maintaining a composting toilet requires a basic understanding of the process of composting and composting digesters.

COMPOSTING AND COMPOSTING TOILETS

Composting is a natural aerobic biological process where bacteria convert organic material into a stable humus product, carbon dioxide, and water. The compost process requires a balance of nutrients, oxygen, and moisture to support the bacteria. Compost toilets attempt to control and accelerate this natural process in a digester chamber consisting of a large container placed under the toilet chute to collect and decompose waste.

Maximum decomposition requires a carbon/nitrogen (C/N) ratio between 25:1 and 30:1[1]. The C/N ratio of human feces is approximately 8:1. The C/N ratio of urine is about 0.8:1. A carbon rich material is added to the human waste to achieve a C/N ratio near 30:1. Carbon and nitrogen provide nutrients for bacteria and mixing the carbon source with the waste material provides the best interface between carbon and nitrogen for optimal bacterial action. The material should be mixed to uniform consistency.

Mixing also helps aerate the pile. The feces, toilet paper, and wood shavings are mixed in the digester to create an aerobic organic mass, or biomass. Fans and air channels control and direct the air flow around this biomass to aid in aeration and evaporation.

Figure 2. The toilet paper, feces, and wood shavings are thoroughly mixed together to achieve an aerated mass of uniform consistency. The biomass is leveled after mixing.

The optimal moisture content for aerobic decomposition is 40% to 50%. Organic waste has a moisture content of approximately 70%; urine is approximately 95% water. The biomass will not decompose aerobically if it is too wet. The carbon source can act as a bulking agent to help lower the moisture content and increase the evaporation rate. Mixing a bulking agent with the feces creates voids for the fan to pull air through. These voids provide a large surface area for evaporation and help drain the liquid waste out of the biomass.

Decomposition will slow and eventually stop if the biomass becomes too dry. If dryness is a problem water may be sprayed across the top of the pile. Reducing the amount of bulking agent will also slow down evaporation. It takes practice to achieve and maintain optimal moisture content.

Decomposition also slows during cold temperatures. Temperatures lower then 4.5°C. (40°F.) will practically stop decomposition. Decomposition will resume when the temperature of the biomass warms up. The warmer the biomass temperature, the faster it will decompose. Average monthly temperatures may be used to estimate temperatures. Without additional heat,

a compost toilet in an area where the yearly average temperature is 13°C. (55°F.) can handle only half as much use as a compost toilet in an area where the average annual temperature is 18°C. (65°F.). The manufacturer, manufacturers' representative, or designer must adjust the published use figures for climate, temperature, humidity, elevation, site type, etc. See appendix A.

Well-decomposed compost or humus is dark gray, crumbly, and earthy smelling with no resemblance to fecal material. It is possible to achieve volume and weight reductions of up to 85 percent of the original biomass. When mixed with top soil, compost is a rich soil amendment adding nitrogen and phosphorus as a natural fertilizer and helps to retain moisture.

The effectiveness of compost toilets is the subject of much research. Many studies document that properly sized, located, and maintained compost digesters destroy pathogens[2,3,4]. Undersized, poorly located, or poorly maintained compost units do not work as well and studies have shown that material removed from these units still has a high coliform content[5,6,7].

NOTE: The compost removed from a compost toilet digester is of unknown quality. Temperature in a compost digester does not get warm enough to meet 40 CFR 503 regulations for composting sludge. This material should not be used as a soil amendment in areas frequented by people or grazing animals without further treatment or testing. In a restricted area the untested compost may be incorporated into the soil, burned, or buried. Untested compost may also be taken to a sewage treatment facility.

FIELD REVIEW OF EXISTING COMPOST TOILETS

A field review of thirty compost toilets was conducted prior to writing this report. All units examined had been in service at least two years, and most for over three years. The units included installations by the Forest Service, National Park Service, other government agencies, and private organizations. Comments included in a survey conducted by the Forest Service Southwestern Regional Office (R-3) on compost toilets were also considered.

Determining the level of function was subjective, based upon the odor and appearance of the compost as well as the liquid level in the clean-out chamber. Information obtained included the amount of use, pile level, date and amount of material last removed, maintenance problems, and recommendations when available.

Figure 3. The hatch access to this basement results in a restricted entry. Basements with restricted entry are confined spaces and must be included on the confined space inventory. These spaces must be evaluated for potential hazards in accordance with 29 CFR 1919.146.

Most of the units observed are failing to achieve maximum decomposition. The following problems were noted:

1. Lack of correct maintenance—no maintenance records kept; no maintenance manual on-site.
   - Incorrect amount of bulking agent.
   - Lack of mixing to break up large particles, aerate the pile, and provide a good interface between the carbon source (wood shavings) and the nitrogen source (human waste).
   - Standing liquid in the clean-out chamber.
   - Biomass too dry.
   - Spiders and rodents in the basement.
   - Vents plugged with leaves, cobwebs, etc.
2. Design problems—sizing and building.
   - Digester too small for volume of use. An undersized digester will result in insufficient time for decomposition. Sizing errors may occur because of unexpected use; i.e., trailheads used as roadside rest areas, or visitors who use the odor-free compost toilet instead of a closer vault toilet.
   - Hatch and ladder access into the basement creates a confined space condition, making maintenance very difficult. See figures 4 and 5.

Figure 4. Hatches make maintenance difficult. They also result in confined space areas.

Figure 5. Ladders create restricted access resulting in confined space entry conditions.

- The basement is just big enough to hold the compost digester. There is no room for maintenance or storage needs. Basements that are improperly designed make maintenance difficult or impossible.

- Incorrect basement drainage. Full basements need a sump and drain or pump to remove water caused by groundwater infiltration or surface water runoff (see figure 6).

- Inadequate lighting impedes maintenance and is a safety issue.

The following comments and complaints were received from maintenance workers:

- "The visitors love them." Visitors frequently comment on the lack of odor in and around compost toilet buildings.

- "The person who designed this basement has never had to take care of a composting toilet." Basement design deficiencies is the most frequent complaint.

- "Our basements are deep, dark, disgusting pits full of rats and spiders. Our basements flood every year and the water gets into the digesters." See figure 7.

- "Our unit is really undersized. We have to empty it three times a season." Undersized digesters are the most frequent problem, and the second most frequent complaint.

Figure 6. Water can infiltrate into basements from ground water or surface water run-off. A method of removing water must be provided in full basements.

Figure 7. This basement is a "deep, dark, disgusting pit." This basement with hatch and ladder access is a confined space.

- "Mixing the stuff is gross." Maintenance workers do not like them. Of the thirty units visited, only five maintenance people preferred them to sweet-smelling toilet (SST) vaults.

- "Get heavy duty, quality fans and pumps. The cheap ones that come with the units burn out too fast. Keep replacement parts on hand." Problems with pumps, fans, and the solar electrical system is the second most frequent problem and third most frequent complaint.

- "Don't get the digester as Government Furnished Material; pieces get lost or damaged during storage."

Some compost toilets visited were installed as an alternate technology experiment. They were installed on districts that had several vault toilets and did not have the additional resources (work force) needed to properly maintain a compost toilet. Maintenance personnel did not like the extra work of a compost toilet. Some of these units are pumped like vaults.

Some maintenance personnel had no training in the proper operation and maintenance of the units. The personnel were hired after the units were installed and had not seen a maintenance manual.

The compost toilets that achieve the best decomposition have the following things in common:

- Maintenance workers and managers that are committed to make them work. They make the necessary time and resources available to maintain the digester.

- Units have adequate, well-lighted basement space to work in.

- Units are in locations where vaults cannot be pumped, sewage cannot be disposed of, or costs of pumping and disposal are too high.

- Workers and managers believe composting toilets are environmentally sound solutions to their waste management problem.

Figure 8. Yoho National Park, Canada.
Recirculating solar heated air and fully insulated foundation keep the biomass warm enough to decompose at this high altitude northern location. The rustic look of cedar slab siding fits in this remote location.

Figure 9. Yoho National Park, Canada. The building, designed by Sunergy Systems LTD, Canada, is fully accessible.

PLANNING CONSIDERATIONS

Composting toilets, along with flush toilets, SST vault toilets, etc., are tools in a toolbox. All available waste management options should be considered during the planning stage. **Maintenance, economics, and aesthetics must all be considered and balanced during planning, for any waste management option.** Initial costs, site limitations, maintenance costs, maintenance time, septage or sludge disposal, and maintenance training needs must be included when considering waste management options.

When selecting a toilet option, evaluate each site with consideration given to user expectations, Recreational Opportunity Spectrum (ROS) Classification, development scale, etc. Site access (vehicle, ATV, pack animal, helicopter), suitability for solar power, season of use, and climate should also be considered. (See figure 8 and 9)
The Southwestern Regional Office recommends using composting toilets:

- When the development scale suggests that a flush system is preferred, but due to water or wastewater problems is not feasible.
- When an SST vault is preferred, but pumping is not feasible or economical. More and more areas are experiencing difficulty disposing of vault septage.
- When odor from a SST vent stack would adversely affect the recreational experience.

DESIGN FACTORS

Digester Size and Volume of Use

Extreme care should be used when evaluating manufacturers' sizing of a compost unit. The published capacity at (18.3°C) 65°F. can be used to compare units, but should not be used as actual capacity. **NOTE: Require and review site specific sizing calculations based on site type, climate, and use patterns.** If a vault gets more usage than expected it can be pumped more often; however, the compost process is not easy to accelerate because of additional use. It is prudent to size the unit for expected future use, not current use.

Toilet use is different from number of visitors. **Use refers to number of times the toilet is used, not number of visitors to a site.** At a campground, each visitor may use the toilet two to three times. If most visitors camp in a self contained RV, few will use the toilet. Length of stay at an area, travel time from and to the nearest town or city, and visitor origin (local, regional, or national) will affect toilet use patterns in day use areas. See appendix A for toilet use patterns.

The amount of material to be decomposed varies significantly depending on day use, night use, or 24-hour use. This is because the urine is drained out of the biomass, and only feces, toilet paper, and wood shavings are retained to decompose. A compost toilet at a campground can only handle one-fourth as much use as a compost toilet at a day use area.

Figure 10. Santa Monica, CA, Rocky Oaks Trailhead. This building with a daylight basement is available from CTS.

Site Selection

If possible, locate compost toilets on sloping ground so the basement can be day-lighted. This not only makes maintenance easier, but also keeps cost lower, requires less mechanical equipment (i.e. pumps), and avoids the problems of confined space entry. Day-lighted basements (figure 10) are less likely to flood than full basements, and gravity drain lines can remove excess liquid from the digester.

The site should be suitable for a small leach field to dispose of excess liquid. This is especially critical in day use areas if excess liquid will be disposed of on-site. A sanitary engineer should be involved in the site selection if a leach field is used.

Choose sites that receive adequate sun to operate a photovoltaic electrical system, or have grid electric power available; ventilation fans and basement lights need electrical power to operate.

Figure 11. Ocean Acres Recreation Area, Stafford Township, NJ. This building available from Clivus™ has stair access to the basement. It is not a confined space area.

BUILDING DESIGN CRITERIA

Basement

Design the basement to make maintenance as easy as possible, (see figures 11 and 12). The basement access should allow unrestricted entry, and should be large enough to replace the digester if required.

Day-light the basement if possible with double wide doors for access. Install stairs if you must use a full basement. **Do not install ladders.** Full basements with ladders or steep stairs are confined spaces as defined by Occupational Safety and Health Administration (OSHA). Removing the composted material from a full basement with a ladder is difficult. The finished product is placed in buckets and carried up the ladder. If the tank has become anaerobic, maintenance workers must carry raw sewage up the ladder, or have the unit pumped. Some units have removed as much as 30 - 5 gallon buckets per year of partly decomposed material.

Provide light in the basement for maintenance and safety. Paint basement walls white to reflect as much light as possible. Lights with timers or motion sensors will not run the battery down if left on. An adjustable spotlight or task light positioned to illuminate inside the digester is useful. Some digester models are available with the task light included.

Figure 12. Organ Pipe National Monument. The double doors on this daylight basement open to allow room to maintain the compost pile. The lower service road provides access to pump the excess liquid holding tank.

Provide a method of removing excess liquid from the digester. (See figure 13.) If possible, the excess fluid should be removed by gravity to minimize maintenance. A hand pump, or electrical pump may be used, but they frequently malfunction. Excess liquid can be disposed of in a leach line, holding tank, or sewer line. If liquid can not be disposed of on site, it may be stored in a small vault for removal, or a unit can be designed to evaporate all of the liquid. **NOTE: Require calculations showing site specific evaporation rates if liquid will not be removed**. To retrofit a unit for liquid removal is more expensive than installing it during initial construction.

Full basements frequently flood, either because of surface water or high ground water. Waterproof the basement. Provide a sump and pump to remove flood water, and slope the basement floor to the sump. If water has entered the digester, it should be disposed of as sewage.

Design the basement area with adequate room to work. (See figures 14 and 15). In high use areas the biomass pile needs leveling daily, and deep-raked once or twice a week. Be sure there is adequate clearance for the rake handle from wall and ceiling. Approximately 2 m (6 ft) is required between the basement wall and access hatch depending on digester configuration. Usually once a year finished material is removed from the bottom of the digester. Allow enough space for a worker to shovel material from the digester into a bucket or barrel. Depending on the digester configuration allow 1.2 m (4 ft) to 2 m (6 ft), from the basement wall to the clean-out hatch to rake finished material from the body of the digester into the clean-out compartment.

Figure 13. Leaking Digester. This digester was equipped with a manual pump. It was pumped every two to three months.

Figure 14. Roosevelt Lake, Tonto NF.
This building was designed with space to work.

Figure 15. Roosevelt Lake, Tonto NF. Storage is available both upstairs and down.
The wood shavings are stored upstairs to make maintenance easier.

Insulate the basement in cold climates, on north slopes, and in areas of heavy cover. Use solar heat collectors to keep the basement or intake air above 10°C. (50°F.) long enough each year to decompose the accumulated biomass. See figure 16.

Figure 16. Nevada Falls, Yosemite National Park.
Yosemite site built compost toilet basement is fully insulated.
Intake air is pulled through a heat collector on the roof.

Allow floor space for a trash receptacle for cans, bottles, and diapers removed from the digester tank, especially if no trash receptacle is provided in the toilet use compartment. Provide **dry** space for bulking material in the basement or in a storage area in the toilet building. Provide storage space for a rake and pitch fork. Install a shelf unit to hold gloves, bleach for cleaning tools, trash bags, etc.

Avoid the following design problems:

- Steep ladders to carrying supplies and equipment up and down.
- Full basements that can flood every year and smell foul.
- Small basements with no storage space and no room to work.

A small, full basement with a steep ladder and inadequate light may be less expensive to build, but is less likely to be maintained. It's good for black widow spiders, rats, and mice but not for maintenance workers.

Toilet Building

Use sound engineering design for the toilet building. Extend eaves to get precipitation away from the foundation. Slope walkways and site drainage away from the building.

Design the toilet building such that the toilet riser is over the impact area of the digester unit, preferably near the center. This will make leveling and mixing easier. Multiple risers may be used on some tanks. Cross connection air flow can result in an odor problem if the risers are in different rooms.

Toilet rooms must conform to universal design guidelines for accessibility. Accessible stalls get more use than non-accessible stalls. This should be considered when locating the accessible riser.

Wall and floor surfaces must be easy to keep clean. Use non-porous, vandal-resistant material. Clean toilets receive less vandalism.

Composting toilet buildings need a source of electrical power. This power can be AC or DC. Electricity operates forced ventilation fans, basement lights, and door counters. Electrical pumps may also be used for excess liquid removal. Pumps may be hand operated or electrical. Specify heavy duty mechanical equipment. (See figures 17 and 18.)

Figure 17. Solar panels mounted on the roof at Organ Pipe National Monument.

Install door counters to minimize the guess work involved in maintenance. Door counters are optional or standard equipment available from most digester manufacturers. The amount and frequency of adding the bulking agent depends on use. Door counters will also alert maintenance workers to an overuse problem before it becomes critical, so they can take mitigation measures. Door counters will help approximate use, but may underestimate use if groups enter the room at the same time, or people are lined up such that a person leaving holds the door open for the next person in line. Strong winds can also cause the door to register false counts.

A storage area in the toilet building is convenient; maintenance workers can store batteries, electrical panels, cleaning equipment, gloves, and bulking agent in this area.

During the design phase consider the steps needed to maintain the compost toilet. The following sequence of activities is required to maintain a composting toilet. The wood chips, cleaning tools, and supplies are stored in a basement with stair access.

Figure 18. Flooded nicad battery bank and controls in a daylight basement. Most locations need batteries to run the forced ventilation 24 hours a day. This installation is by ACS.

1. Enter the toilet room to check fan draw. **Do not enter a full basement if the fan is not functioning.**

2. Climb down the stairs into the basement to check door counter, level the pile, and get wood shavings.

3. Carry the wood shavings up the stairs. Enter the toilet room to pour wood shavings through the toilet riser. Lock the toilet door.

4. Climb down the stairs into the basement to rake or mix the pile. Perform routine checks of the mechanical and electrical systems. Record toilet use and maintenance. Perform routine housekeeping to clean the basement. Gather cleaning supplies to clean toilet room and toilet paper to restock the dispensers.

5. Carry tools and supplies up the stairs. Enter toilet room for normal housekeeping and restock toilet paper.

6. Carry tools down the stairs to storage room.

7. Climb up the stairs. Lock the access door.

Basement and building design, location of storage area, and basement access have a major influence on the time and effort it takes to maintain the compost toilet. An upstairs storage area will save a lot of work and time.

Figure 19. Stairs look steep after three trips down and up.

HEALTH AND SAFETY

All maintenance workers should follow local or regional policy as well as the Forest Service Health and Safety Code Handbook. Each supervisor should complete a job hazard analysis to address standard hygiene requirements, personal protective equipment requirements, confined spaces, and disease prevention.

Figure 20.
Waterless disinfectant hand cleaner and paper towels are conveniently mounted inside of the daylight basement at Nevada Falls, Yosemite National Park.

Good hygiene practice is the best way to prevent illness. Do not eat, drink, or smoke while maintaining toilets. Wear latex gloves, even under rubber or leather gloves, when maintaining toilets. Wash your hands with a disinfectant soap and water after removing gloves. If no water is available at the site, use a waterless disinfectant hand cleaner. (See figure 20.) Wash with soap and water at the first opportunity.

Personal Protective Equipment (PPE) and tools used to maintain a toilet should be considered dirty. Store them at the site if possible. Place them in a plastic bag, dedicated box, or compartment if they are to be removed from the site. Do not use them for anything other than cleaning toilets. Wash coveralls in hot, soapy water after use.

Confined Space

A full basement with an access hatch, ladder, steep stairs, low head room, or other egress/exit restriction is a confined space. Complete a confined space hazard analysis and follow OSHA confined space regulations. **Construction of new units should avoid confined spaces.** Provided adequate light in confined space areas. Industrial standard stairs **do not** cause restricted entry conditions.

All components of the ventilation system should be accessible without entering a confined space basement. Electrical enclosures and batteries may be in locked boxes outside the building or in a secure building storage area.

Bloodborne Pathogens

OSHA and the Centers for Disease Control and Prevention do not consider most sewage/sanitary workers to be at an increased risk from blood borne pathogens. Units that experience a high needle disposal problem are at risk. Follow guidance provided by Forest or Regional Policy, as well as the Health and Safety Code Handbook.

Hatches and Manholes

Open hatches and manholes must be properly guarded with railings or other barriers to protect against falls and also protect workers from foreign objects entering the opening.

Figure 21. This building is located on flat ground and has restricted basement access, but all components of the electrical and ventilation system are serviceable without entering the basement. Building by BMS.

MAINTENANCE AND OPERATION

Start-up

All digester tanks need initial bedding material to establish required air flow patterns. The initial bedding may be moistened wood shavings, peat moss, or a moist mixture of peat moss, wood shavings, and composted manure. Most smaller units need 0.3 to 0.4 cubic meters (8 to 12 cubic feet) of starter mix. Larger units need up to 1.3 cubic meters (45 cubic feet) of starter mix. **Follow the manufacturer's recommendation on the amount and type of material to use.**

Tools

Most manufacturers supply a raking/mixing tool with their unit. One manufacturer offers a system with the maintenance tools built in. A raking/mixing tool can be fabricated by bending the tines of a long tine pitchfork 90 degrees. A shovel is used to remove finished material from the clean-out chamber. A garden rake is useful to pull material into the clean-out chamber. Use a mechanical liter picker to remove cans and other non-degradable material from the digester. Place any trash removed in a plastic bag lined garbage can with a tight fitting lid. In hot or dry climates, if the unit is not equipped with an internal spray system, a five-gallon (18.9 L) spray can or fire-fighter portable water unit should be available to add moisture to the biomass. Most manufactures offer internal spray systems as either standard or optional equipment.

Use a broom and dustpan to clean up wood shavings that spill on the floor. Mop concrete floors to keep them clean. Clean the outside of the digester with a rag and 3D solution (detergent, disinfectant, and deodorant). Wipe the handles of tools used in the tank with a rag and 3D

solution. Store tools used in the tank in a disinfectant solution of ten parts water to one part household bleach. Keep the basement area clean. Tools are stored inside the digester, suspended from the top of the tank in the Yosemite National Park site built composters. See figure 22.

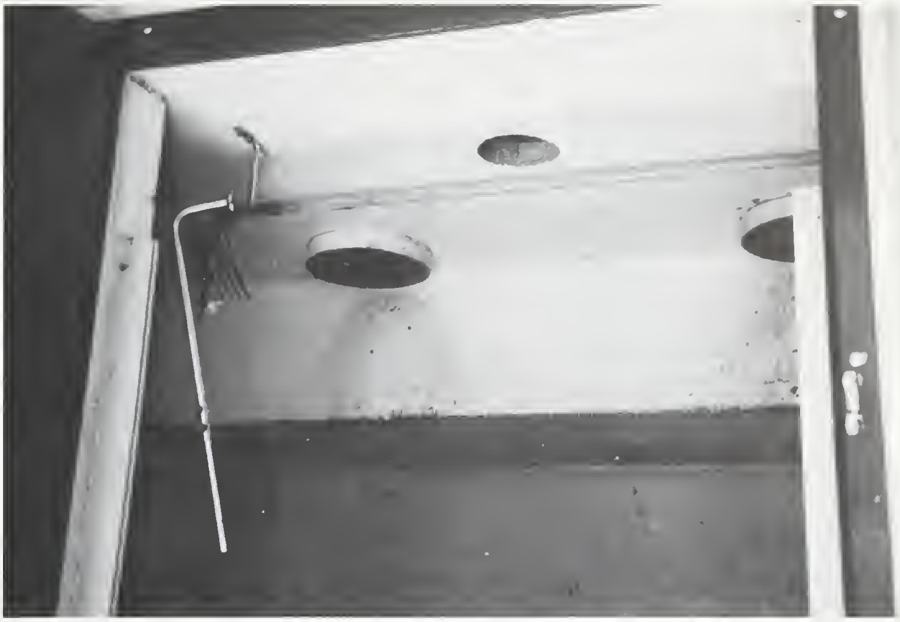

Figure 22. Tools suspended inside of digester at Nevada Falls, Yosemite National Park.

MATERIALS

A high carbon source bulking agent must be added to raise the C/N ratio. Pine or fir wood shavings have a C/N ratio between 500:1 and 700:1. Bark mulch has a C/N ratio of 200:1. **Do not use cedar, cypress, or redwood products.** Rice hulls, chopped corn stalks, or chopped straw may be used, although planer shavings are preferable. Do not use grass clippings or leaves because they are difficult to mix and will pack into a mat. They add carbon but do not provide the bulking needed to control moisture and air content.

Earth worms can be added to the bottom of the tank to continue breaking down the organic material, but they will not live if the biomass is saturated with urine. Biological additives formulated for compost tanks can be added to increase the composting rate. These are particularly useful to restart a unit in the spring if the tank froze over the winter.

Routine Maintenance

Keep the toilet use compartment clean and stocked with toilet paper. Clean toilets are less likely to be vandalized than dirty toilets. Refer to 'Cleaning Recreation Sites', available after July, 1995, from the San Dimas T & D Center, for detailed directions on cleaning toilet buildings. **Keep disinfectant out of the digester tank.**

Check fan operation. Insure the fan is operating before entering a confined space basement. ****If the fan is not operating, do not enter the basement**. ** To make sure air is moving, hold a piece of toilet paper across an open toilet riser and the fan should pull the toilet paper down. Cobwebs, leaves, and other debris can plug the vent. If the fans are running but no air is moving, clean the vents with a chimney brush.

Digester Tank

Monitor and adjust the C/N ratio, moisture content, and air content during routine maintenance. The biomass pile should appear damp, of uniform consistency, and "fluffy", not wet, soggy or compacted.

After leveling the pile add 3L to 8L (one to two gallon size scoops, 39 oz. coffee can) of dry wood shavings for each 100 uses since the last maintenance. For 200 uses use 6 L to 16 L, and for 500

Figure 23. Internal fresh water spray system standard on DEVAP™ 2000 tank by Biological Mediation Systems, Inc. (BMSI).

Figure 24. Fresh water storage tank by BMSI.

uses use 15 L to 40 L, etc. Check the door counter to determine usage. Use campground visitor records to approximate use if there are no door counters. Install door counters if other visitor records are not available. Keep a record of the date, door counter reading, and amount of wood shavings added. Level the waste pile and pour the wood shavings through the toilet riser daily, or each time the toilet is cleaned.

Once a week, mix the wood shavings and feces thoroughly, breaking up large clumps. The biomass should have a uniform "fluffy" consistency. Adjust the amount of bulking agent, with 3 L/100 uses (1 gallon/ 100 uses) on the lower side and 8 L/100 uses (2 gallons/ 100 uses) on the higher side, to help control moisture and air content. Add more bulking agent if the pile is sticky, soggy, or compacted. Decrease the amount of bulking agent used if the biomass is routinely dry. Consider using bark chips instead of wood shavings if the pile is consistently too wet. Use twice as many bark chips as wood shavings. Review maintenance log to determine why the moisture content is continually wrong. Rake inorganic material (i.e., cans, bottles, plastic) into a corner to dry before removing. Use a litter picker to remove inorganic material from the digester tank.

Maximum decomposition requires a moisture content of 40 to 50 percent. This has been described as the consistency of a damp, but not soggy, sponge. Spray water on the biomass if it is too dry. Optional automatic spray units are available for some compost digesters. The automatic spray tank must be checked and filled as needed. Fresh water will not result in a salt build-up that leachate respray can cause. A salt build-up can slow decomposition. Mix additional wood shavings with the biomass if it is too wet, and review maintenance logs to determine the cause.

Studies of a time/temperature curve done by Yosemite National Park showed that the temperature of the biomass increased after mixing. The biomass temperature dropped immediately after mixing, then steadily increased and peaked within five to seven days. Once a week, mix the top two feet of material thoroughly for the most rapid decomposition. Move material forward from the back, then backward from the front. Pull from the sides of the tank into the middle. Repeat until a uniform, fluffy consistency is achieved. Level the pile after mixing.

If the biomass compacts, or appears soggy insufficient bulking agent has been added. Add more bulking agent and mix again. Mixing incorporates air into the biomass, promotes drainage, and provides the best interface between the carbon and nitrogen. Tanks that receive light use may be mixed every other week, depending on manufacturers recommendation.

Monitor the liquid level in the clean-out chamber; remove any standing liquid; find the cause of the standing liquid; clear the drain; and check the pump. (See figure 25.)

Clean the basement floor of any spilled wood chips, water, leachate, or compost. Clean the outside of the digester tank as needed. Take rodent abatement measures if mice or rats have moved into the basement. Repair entry holes and use traps or poison to control the rodents. Contact pest management before using poison. Patch rodent access holes with flashing metal or heavy screen. Store the wood shavings in a tightly closed container to prevent rodents from nesting in it. Keep a No Pest Strip in the basement.

Figure 25. The pump filter was clogged in this tank. Leachate was dripping on the floor before it was noticed.

Service vent stacks and fans annually. Inspect the fan blades for damage and remove accumulated dust. Clean the vent stack with a chimney brush. Inspect the electrical system for corrosion or frayed wires.

Keep a record of date of maintenance, use since last maintenance, type of maintenance, condition of biomass, amount of wood shavings added, amount of water added, amount of excess liquid removed (manual pump), liquid level in the holding tank (if installed), odor, and other information (worms add, biological additives, insecticide used, inorganic material removed, etc.). The records are important to keep track of increased or decreased maintenance needs, materials and supply needs, and problems that may arise. A permit to dispose of the finished material in other than a sewage treatment plant may also need maintenance records.

The manufactures operation and maintenance manual should be at the site. Also, a locally developed plan that includes the job hazard analysis, confined space information, compost disposal, etc. should be developed. Keep records showing that the O & M manual was followed. Most states require these records for a disposal permit.

Clean-out

Follow manufactures recommendations for removing finished compost. When the biomass is level with the maintenance hatch (for vertical and sloped base composters), or two feet below the toilet riser, remove only enough material from the clean-out chamber to allow a season of use. Do not empty the digester. Finished material is usually removed once a year, after the digester becomes full. The amount of material to be removed will depend on size of the digester tank, amount of use, and amount of decomposition—usually less than 15 cubic feet. Remove the composted material in the spring, or just before the season of maximum use. If the compost is too dry, it may bridge (fail to slide down the sloped tank floor), then collapse in a way that mixes new waste with older material. See figure 26.

In units that receive little use it may not be necessary to dispose of any material for several years. Follow the manufacturers recommendation. Removing some material and recycling it through the toilet riser will help keep the bottom layer from becoming compacted in vertical and sloped base composters.

Figure 26. Un-decomposed material in clean-out chamber caused when bridged material collapsed.

Disposal

Well maintained composting units can produce a final product that is low in pathogens and organically stable and suitable for use as a natural fertilizer or soil amendment. Sites suitable for use include forest land or agricultural fields not used for growing root crops for human consumption. Compost is also valuable for the restoration of abandoned rock quarries, old mine sites, or slide areas, although the compost removed from a composting digester is of unknown quality. Composting digesters rely on time and a hostile environment to destroy pathogens. Overused units do not allow adequate time to ensure pathogen destruction.

Temperatures in compost digesters do not usually meet those required in 40 CFR 503 under Processes to Significantly Reduce Pathogens; however, some compost units have achieved pathogen and vector attractant reduction consistent with Other Methods. 40 CFR Part 257 and 40 CFR Part 503 govern surface utilization and disposal regulations. A state permit should be obtained for beneficial use of the compost and records should be kept that document fecal coliform levels for land application (incorporation in the top soil). A pasteurization unit is available to treat the compost that meets 40 CFR Part 503 Class A standards.

The composted material may be shallow-buried in an area away from water resources, if the ground water table is not high. 40 CFR 257 discuses regulations. Contact your local EPA office for permit.

Forest plans, unit policies, or State agencies may not allow surface disposal or shallow burial of composted material. If this is the case, the material must be disposed of in another approved manner. Some municipal plants and landfills may refuse to take the compost because the high solids content of the material can overload some small sewage treatment plants. Long-term compost disposal should be thoroughly considered during the planning stage of the project.

SUMMARY

Composting toilets have a place among Forest Service human waste management options. Even units that are failing to achieve maximum decomposition may be considered partially successful, if visitor satisfaction is the highest priority.

Composting toilets should not be arbitrarily selected as the option of choice. All waste management options should be considered during the planning stage and the most appropriate option selected for the site. Composting is the method of choice when:

1. It is not economical or feasible to pump a vault.

2. A flush toilet is preferred but not feasible.

3. Odor from an SST toilet vent stack would adversely affect the recreational user.

Consider the advantages and disadvantages of composting toilets compared to other waste management methods.

Advantages:

- Functioning compost toilets are odor free in the use compartment. Very little offensive odor vents to the outside.

- They have very high customer satisfaction.

- Composted sludge may not need to be removed for several years (depending on level of use).

- A properly functioning compost digester reduces the mass, weight, and odor of fecal material.

- The material removed from a functioning compost digester can be disposed of by incorporation into the soil or burying near the site (depending on regulating agency, unit policy, and location).

All of the advantages of compost toilets are lost if they are designed without special attention to maintenance. The additional design time spent making an aesthetically pleasing compost toilet building functional is well worth the effort.

Disadvantages:

- Compost units cost more. Initial cost of composting toilets can be $5000 to $10,000 more than the same building design for a vault toilet.

- Annual operation and maintenance cost of the compost digester is $500 to $1000 per year (not including routine cleaning and stocking of toilet paper). This varies by season of use and cost of wood chips or other bulking agent. The cost to pump a vault and dispose of the sewage is about $100 per year (varies widely in some areas).

- Composting toilets need an increase in maintenance time of 1/2 hour to 2 hours per week. With staff cutbacks and overworked maintenance personnel, this is a big disadvantage.

Cleaning out a compost digester that is not working due to over use, equipment failure, lack of maintenance, or chemical contamination, is an extremely odious job. Maintenance workers shovel the raw sewage out of the tank (into buckets or barrels) and transport it to a sewage disposal facility.

Proper maintenance of composting toilet requires adequate staffing, training, and funding. The biomass needs consistent maintenance to keep it aerobically composting. If the maintenance personnel can't or don't spend the time to maintain the unit, it will become septic or anaerobic. Maintenance workers should be involved in the decision to install a compost toilet, and should have the opportunity to visit a properly operating unit and talk to the maintenance staff.

Attention to maintenance requirements is critical during the design of a composting toilet. Do not allow aesthetics to take precedence over the function and maintenance of any type of toilet system. A beautiful building that smells bad or doesn't work will not meet visitor expectations.

Consistent routine maintenance is vital to the operation of compost toilets. A knowledge of the composting process will help maintenance workers recognize and correct problems before they become critical. A complete operation and maintenance guide should be present at each site and office.

MANUFACTURERS
Composting

Any of the following compost digesters can achieve a satisfactory level of decomposition when correctly sized for use and climate, and properly maintained.

Advanced Composting Systems (Phoenix)
195 Meadows Road
Whitefish, MT 59937
Phone (406) 862-3854

Material: The Phoenix digester tank is manufactured from rotationally molded polyethylene with 1/4 inch exterior shell and integral foamed polyethylene interior insulation layer. All fasteners and internal parts are stainless steel or plastic. The tank is vertical with a flat floor, and a sloping false floor to allow liquid separation. It's disassembled for shipping and assembled at the site. The maintenance hatch opening is 11"X 17". The cleanout hatch opening is 11" X 17".

Figure 27. Phoenix Model PF200.

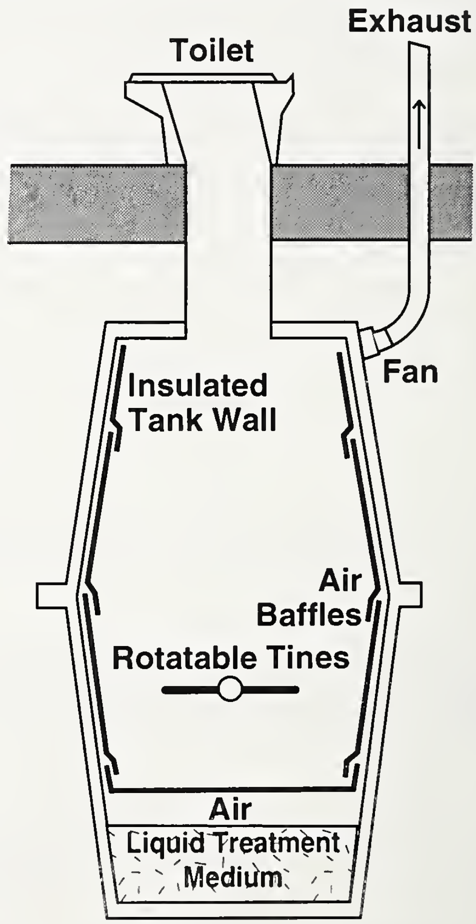

Figure 28. Diagram of Phoenix Tank.

Models: The Phoenix digester is available in two sizes. The PF200 is 3'X 5'X 6' with a **usable** volume of 350 gallons. The PF 201 is 3'X 5'X 7.5' with a **usable** volume of 500 gallons. The listed capacity at 65° F. average annual temperature is 50 uses per day for Model PF201.

Unique Features: The Phoenix digester is insulated to minimize heat loss. An automatic liquid respray system maintains pile moisture. Continuous side wall air baffles help aerate the pile. Rotating tines control movement of the composting material and keep the newest material separated from the oldest material. The tines also minimize bridging problems that can occur when the biomass is too dry. An elevated, sloping floor at the bottom of the tank provides liquid storage. Liquid is treated and filtered through a stable, aerated medium.

The basic package includes all hardware and components necessary for installation and operation: digester tank, plastic toilet, toilet chute, maintenance rake, trash remover, liquid respray system, complete vent system, and door counter. The warranty on the tank, plumbing, and electrical components is 5 years.

A solar electrical system and additional fixtures are available options. A liquid evaporation system and holding tank are available for locations that require zero discharge on site. A pasteurizer is available to treat final compost to meet CFR 503 Class A standards. A computer control system is available to manage the photovoltaic system and electrical loads, monitor and record use, and record environmental data.

Figure 29. Smith Rock State Park, construction photo. Two Phoenix composting tanks, with two toilets, photovoltaic electrical system, compost pasteurizer, liquid evaporator, and an active solar collector built into south roof. Rainwater catchment system collects fresh water from the roof.

Figure 30. Smith Rock State Park, finished toilet building.

Buildings: Complete buildings are available for any location including remote sites. Complete facilities can include photovoltaic electrical system, rainwater catchment/cistern, energy efficient lighting, and evaporation system.

Forced air can bypass the lower vent when toilet seats are left open. Liquid respray may result in a high salt content in the biomass that may slow decomposition.

Clivus Multrum, Inc.
P.O. Box 127
North Andover, MA 01845
(508)794-9400
1-800-425-4887

Figure 31. Clivus® Tanks, M35, installed.

The Clivus® tank is molded from high density cross-link polyethylene with a sloping base. Some models are factory assembled, but most are assembled at the site. Twelve different models are available. Tanks are available from 61" to 99" high, with volumes ranging from 39 cubic feet to 203 cubic feet. Listed annual use capacity ranges from 7200 to 65,000 at 65° F average annual temperature. The maintenance hatch openings are 10" X 20" or 10″ x 30", depending on the model. The cleanout hatch opening is between 40" X 28" and 63" X 32".

Clivus Multrum, Inc. is the oldest compost manufacturer with the largest product line available. Several Clivus® models have the National Sanitation Foundation (NSF) certification.

The Clivus® basic package includes digester, internal ventilation systems, starter bacteria, cleaner, and a maintenance tool. Optional items available include fixtures, support cradle, starter bed, external vent system, liquid evaporator, moistening system, door counter, external vent system, solar system, starter bed, and liquid removal and treatment system. There is a five-year limited warranty on the digester tank, and a one year warranty on electrical components. Complete buildings are available in wood, concrete, or steel, with wood or concrete basements. Forced air can bypass the lower vent when toilet seats are left open. This ensures an odor-free user compartment. The manufacturer claims that it does not slow decomposition. Bridging can occur if the biomass becomes too dry and fails to slide down the sloped floor. Manufacturer suggests spraying the biomass with water and letting stand a few days if this happens.

Figure 32. Alabama River Lakes, U.S. Army Corps of Engineers. Bilco doors into basement and stair access avoid a confined space area. Building from Clivus®.

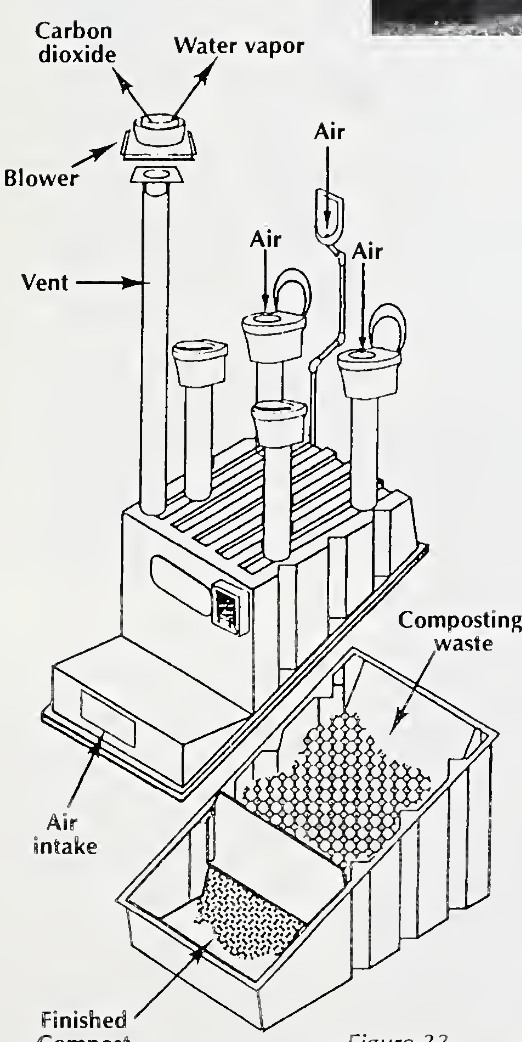

Figure 33.
Clivus® Tank Air-flow Diagram

Composting Toilet Systems (CTS®)
PO Box 1928,
Newport, WA. 99156-1928.
Phone (509)447-3708

The CTS® digester is a fiberglass tank with a sloping base. Site assembly of the tank is required. Five models are available. Tank heights range from 5 feet to 8 feet. The CTS®-1010 has a volume of 141.5 cubic feet, with a listed use capacity of 27,000 uses per year. Other units are available with use capacity from 6500 to 43,800 uses per year. The access/maintenance hatch is 18" X 36", and the cleanout hatch opening is 31" X 16".

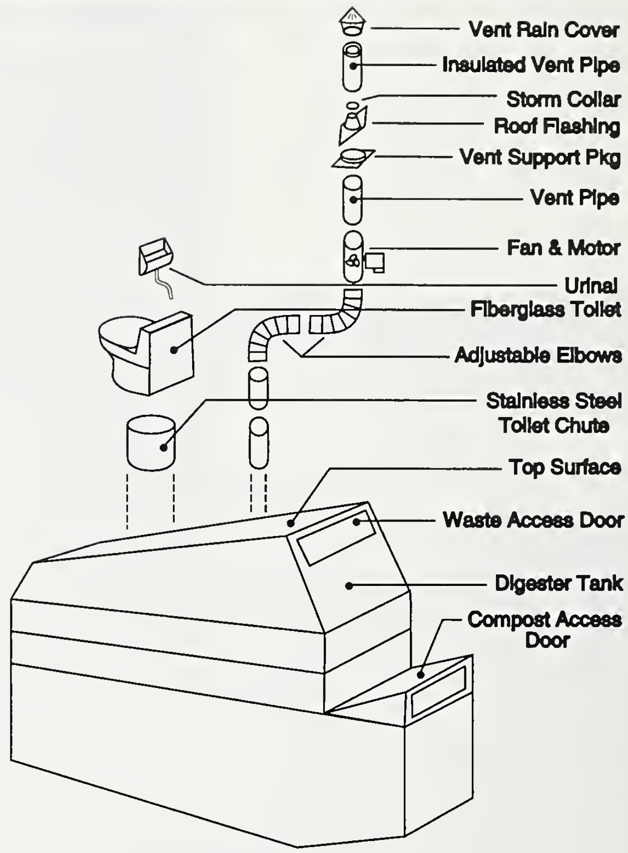

Figure 34. CTS®-904 Digester Tank Diagram

The CTS® digester has a configuration similar to some Clivus® models. Several CTS® models have the NSF certification. Forced air can bypass the biomass when toilet seats are left open. Bridging can occur if biomass becomes too dry and fails to slide down the sloped floor.

CTS® 1010 basic kit includes the digester tank with assembly hardware and drain, one stainless steel toilet assembly, complete interior and exterior vent system, initial bedding material, and the tank cradle. Optional items include alternate fixtures, liquid removal pump, and solar electrical system. The digester is covered by a five-year limited warranty. Complete cedar building and pressure treated basements are available.

Figure 35. Table Rock Lake, Branson, MO.
Building from the CP-Line available through CTS®.

Dehydrating/ Composting Units

The stabilization of organic waste is a combination of dehydration and bacterial digestion (composting). Dehydrating/composting toilets combine principles of composting with principles of dehydration in an effort to achieve the optimal balance for the greatest total reduction in weight and volume.

Bio Sun
RR #2, Box 134A
Millerton, PA 16936
Phone (717)537-2200

The Bio Sun Waste Reduction System™ (WRS™) tank is molded in a single piece of reinforced, recycled, high density, linear polyethylene. Tank configuration is horizontal with a flat base. It comes completely assembled. Three sizes are available, 4' to 5'6" high. WRS™ 500 models have a usable volume of 56 cubic feet WRS™ 1000 models have a usable volume of 112 cubic feet. A larger WRS™ 1500 model is available. The listed use capacity of the WRS™ 500 series is 65,700 uses per year, maximum. The listed use capacity for WRS™ 1000 series is 91,250 uses per year, maximum. The maintenance access/cleanout hatch is 30" X 37".

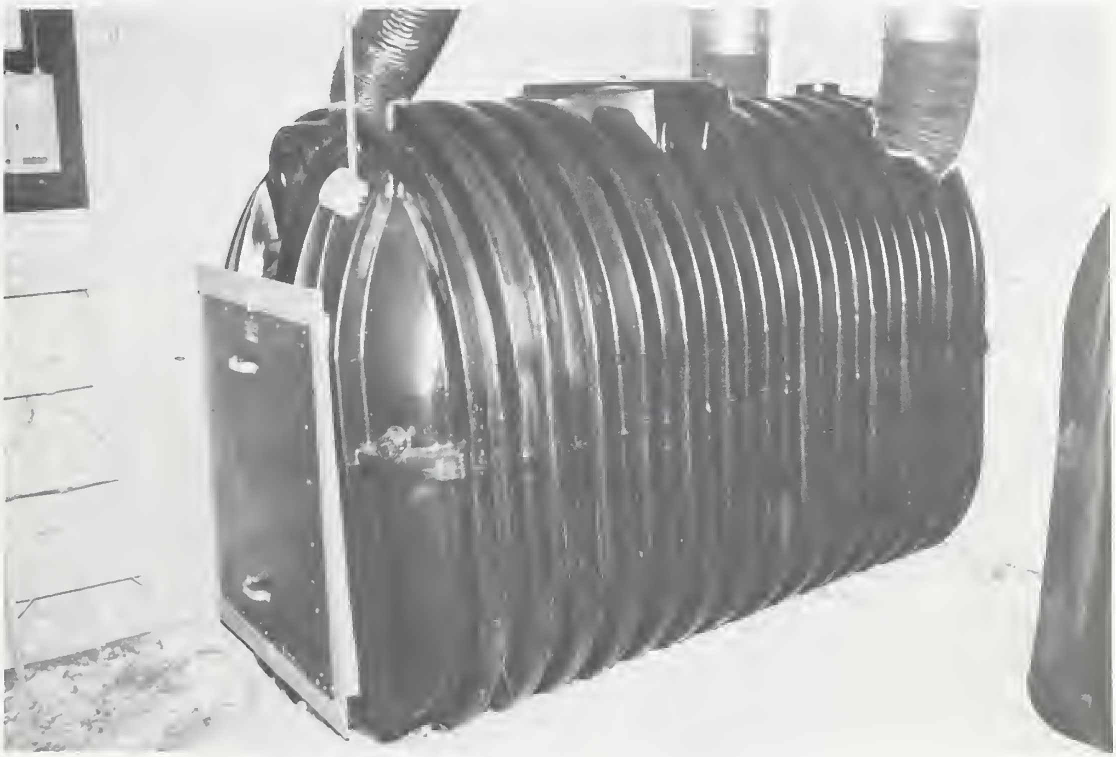

Figure 36. WRS™ 1000 tank, installed.

Direct burial units are available. The WRS™ 1000P has a high evaporation rate achieved using a high speed fan capable of 800 CFM air flow. A level switch starts the Vap-O-coR™ vaporizer when excess liquid is in the liquid holding tank. An Airliner™ cradle increases the air to waste interface. The ventilation system is designed to prevent air from bypassing the biomass when toilet seats are left open.

The Bio Sun basic kit includes the digester tank, complete vent system, control panel, and hardware. Optional items include fixtures and a solar electrical system. There is a 5-year warranty on the digester tank, plumbing, fixtures, and ventilation system and a 1-year warranty on the electrical system. A complete wood building is available.

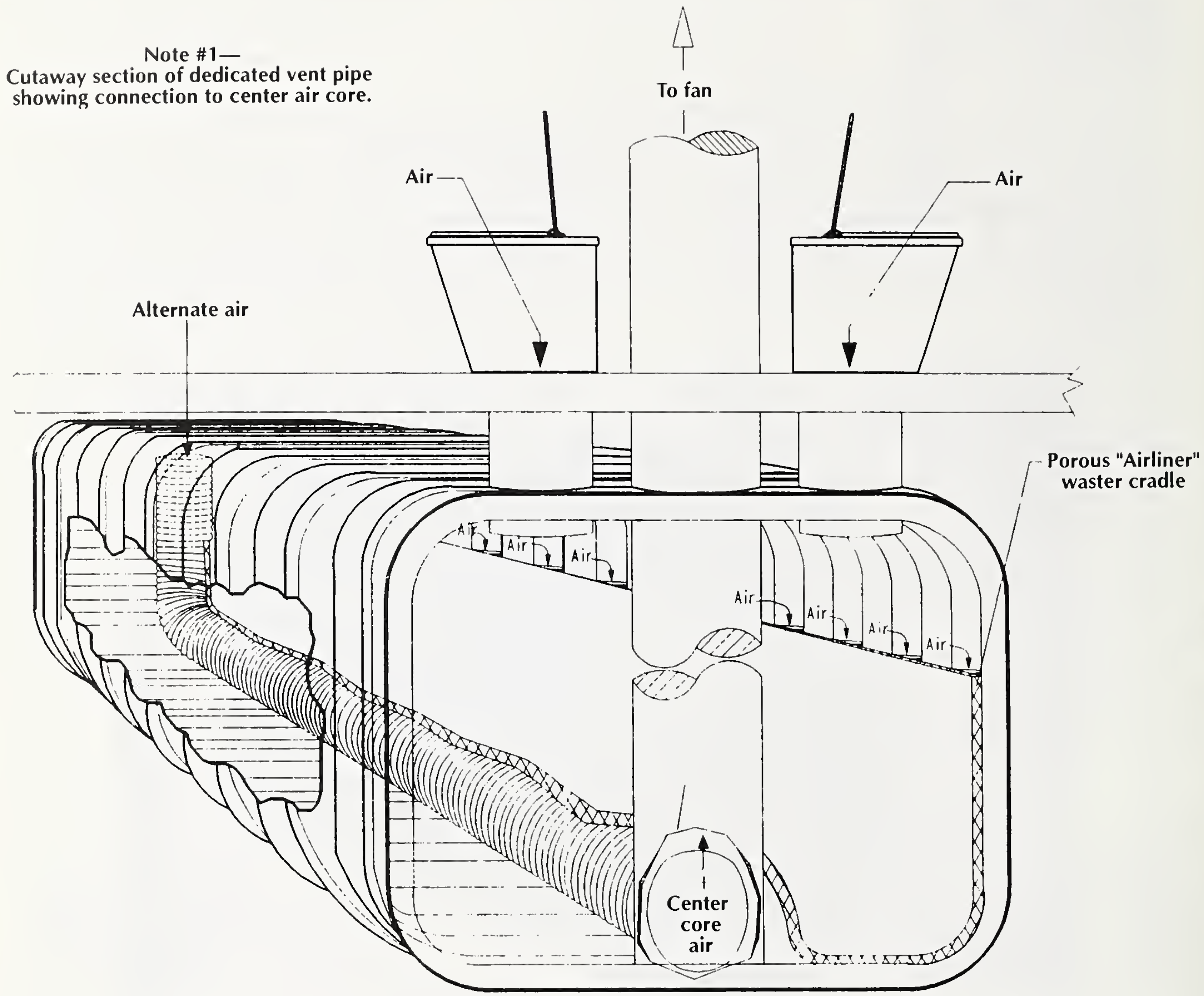

Figure 37. Diagram of the WRS™ tank. Exhaust air is pulled from the bottom of the tank, preventing 'short-circuiting' of air when the toilet lid is left open.

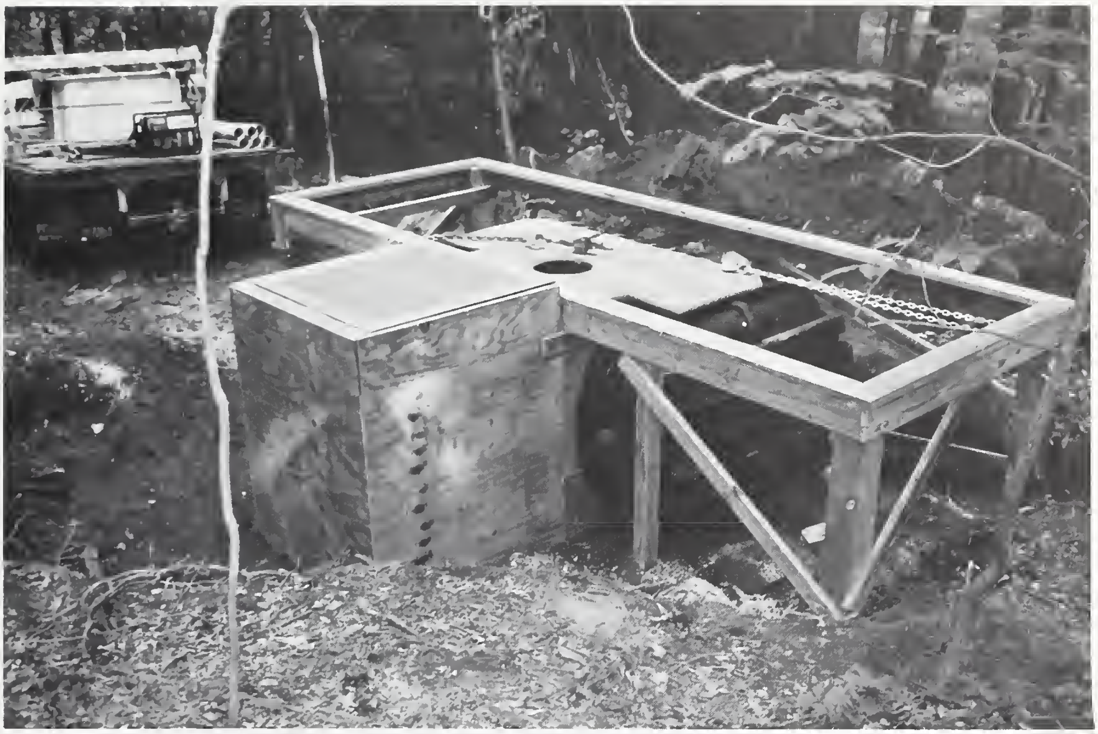

Figure 38. Direct burial WRS™ tank, construction photo.

Figure 39. Vap-O-coR™ vaporizer

Biological Mediation Systems, Inc. (BMSI)
PO Box 8248
Fort Collins, CO 80526
Phone (303) 221-5949 or
1-800-524-1097

The Devap™ 2000 tank is made of vacuum molded Lustran™ ABS plastic resin. The tank configuration is horizontal with a flat base. It is available preassembled or site assembled. The unit is 5 feet high and has a total volume of 203 cubic feet. The liquid holding tank is 137 gallons. BMSI does not publish a "use capacity" due to the number of variables that affect the waste reduction rate. They will calculate a site-specific use capacity when given site type, climate, elevation and seasonal use information. The unit has two access/maintenance hatches that are 13 3/8" by 30" each and two 8" diameter hatches. The upper access door has windows. The warranty on the tank is five years; plumbing and electrical components is one to two years.

This unit has a high evaporation rate achieved through a patented Devap™ System. The ventilation system is engineered and will control internal air circulation with the toilet seat up or down. Outside ambient air is used, minimizing the effects of a cool basement on the system.

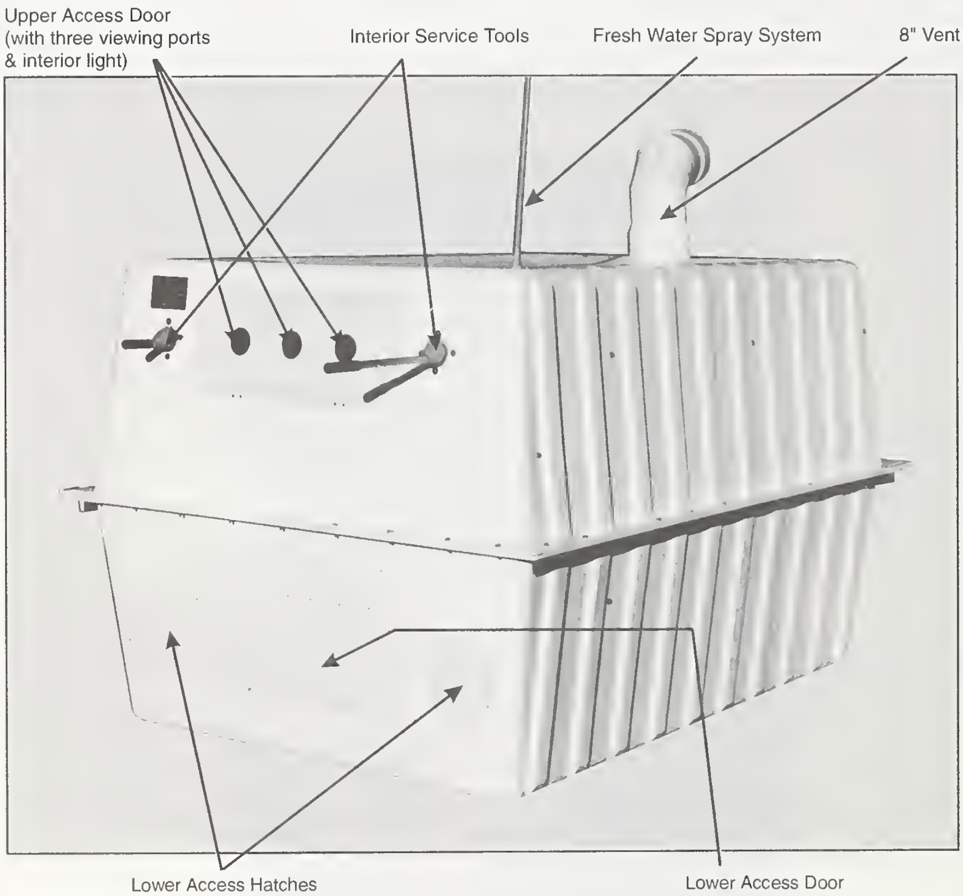

Figure 40. The Devap™ 2000 system has internal service tools, fresh water spray system, interior light, and viewing ports in the upper access door. Most routine maintenance can be done without opening the access door.

The basic Devap™ package includes the reduction tank, two internal service tools (these are not removed) internal and external vent system, automatic fresh water spray system, internal light, control panels, and maintenance manual. Optional items include fixtures, solar electrical system, and greywater systems. Complete building plans and prefabricated building kits are available.

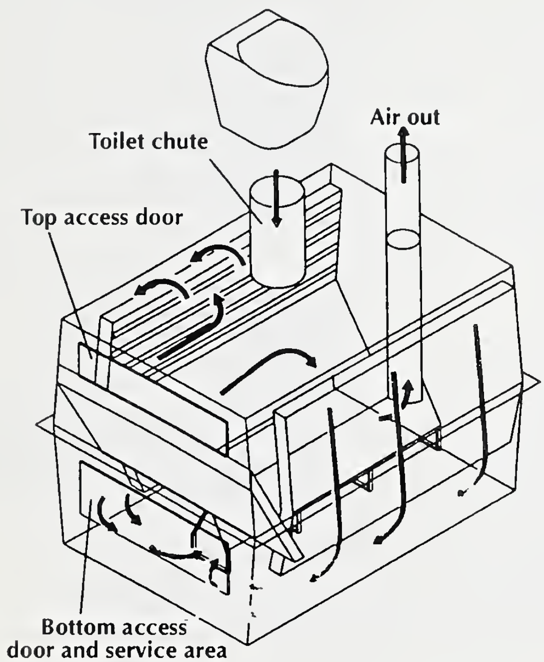

Figure 41. Devap™ Air Flow Diagram. Exhaust air is taken from the bottom of the tank, preventing 'short-circuiting' of air when the toilet lid is left open.

Figure 42. Complete Buildings are available with a utility room. The ventilation and electrical systems are accessible from this room.

Yosemite NP Custom Design
Plans available from Yosemite NP
PO Box 577
Yosemite, CA 95389

This unit is a full basement design with a capacity of 300 cubic feet and a 250 gallon. liquid storage. This is a day use facility installed at the top of Nevada Falls and gets 400 visitors per day, or 60,000 visitors a season. The facility is equipped with a heat collector to aid in the evaporation of excess liquid and a re-spray of leachate used to keep the biomass damp.

The Yosemite Composting toilet was designed with function and ease of maintenance as priorities. It has a large access/maintenance hatch, liquid storage area, and clean-out hatch. The ventilation system prevents air from bypassing the biomass when the toilet seats are left open.

Figure 44. Yosemite National Park Site-built Composting Toilet, basement. This site-built composting toilet has large access doors for maintenance.

Figure 43. Yosemite National Park Site-built Composting Toilet, basement. The daylight basement has double doors that open to increase the maintenance space.

APPENDIX A
Design Numbers [8,9]

The following information is given to help approximate use patterns. In 24 hours, one person produces an average of 0.95 liters (1 quart) urine, and 0.25 liters (1/2 pound or 1 cup) feces for a total of 1.20 liters (0.3 gallons or 0.042 cubic feet) of waste. Approximately 75% of fecal waste occurs between late evening and early morning hours. Add 3 to 8 liters (1 or 2 - 39 oz. coffee cans) of wood shavings for each 100 uses or 24 liters (6 gallons) of human waste. Adjust the amount of carbon source/bulking agent used to control drainage and aeration.

When a compost toilet is used to replace a vault, use vault pumping records to estimate use. 1500 uses equals approximately 380 liters (100 gallons). A 2800 liter (750 gallon) vault that is pumped once a year gets about 11,250 uses. If the vault being replaced was an old, smelly vault, the new compost toilet will get more use. If the old vault leaked, or received RV waste, the estimate will be less accurate.

All use is not equal in a compost toilet. The amount of material to be decomposed varies significantly depending on day use or night use, and length of stay. This is because the urine is drained out of the biomass, and only the feces, toilet paper, and wood shavings are retained to decompose. The amount of feces per 100 uses is greatest at an overnight campground, and least at a day use area. One suggestion is to divide the manufacturers recommended capacity of a compost digester by three for an overnight campground (or multiply expected use by three). Requesting information about the manufacturers basis for "use"; i.e. amount of liquid, feces, wood shavings, and toilet paper would help to evaluate site specific submittal.

Temperature affects the rate of decomposition. The warmer the biomass temperature, the faster it will decompose. Decomposition virtually stops if the temperature drops below 4.5°C (40°F). Many compost manufacturers base their listed capacity on an average annual temperature of 18.3°C (65°F). Although the rate that decomposition slows down is not a straight line, for estimating purposes reduce the manufacturers suggested capacity by one-half for every drop of 5.5°C (10°F).

The type of campground affects use. Toilets at a campground that serves mostly tent campers get significantly more use than campgrounds that serve mostly motor homes and self contained recreational vehicles (RV's).

A contract for a compost digester should require bidders to submit site adjusted use information. Never purchase a composting digester without having a site specific evaluation from the manufacturer or manufacturers' representative.

DESIGN EXAMPLE

NOTE: THIS DESIGN EXAMPLE IS TO DEMONSTRATE THE IMPORTANCE OF A SITE SPECIFIC DESIGN. NEVER RELY ON PUBLISHED MAXIMUM USE NUMBERS WITHOUT SITE SPECIFIC CALCULATIONS. DIFFERENT DIGESTER BRANDS HAVE DIFFERENT AIR FLOW PATTERNS, BIOMASS SURFACE AREAS, AND BASIC LOADING RATES. THE CONTRACT SHOULD REQUIRE SITE SPECIFIC DESIGN CALCULATIONS BE PREPARED AND SUBMITTED BEFORE AWARDING THE CONTRACT. THE DESIGN SHOULD TAKE INTO ACCOUNT SITE TYPE, AREA CLIMATE, AND SITE USE PATTERNS.

The information presented is to show the potential difference between listed capacity at **(18.3°C) 65°F average annual temperature at two local sites. The examples do not include all variables, such as the effect elevation, sun exposure, wind, and humidity can have on a system.**

Select a compost digester for the following site.
Site Type: A family tent campground, with an average 4 people per site, 15 sites.
Site Utilization: 50% on weekdays, and 100% on weekends
Season of maximum use: Memorial Day through Labor Day

Recommendation—Campgrounds receive three times as much fecal material per use as day use areas; divide manufacturers recommended use numbers by three. (This depends on what the manufacturer used as a basic loading rate).

Assumption: Tent campgrounds average 3 uses per person

From Forest Service Manual (FSM) 2330, one toilet riser per 35 People at one time (PAOT), 500 feet (152.4 m) from farthest served campsite to toilet.

PAOT= 15 sites times 4 people per site = 60 PAOT, use one male and one female toilet.

Use per Week = 60 PAOT times 3 uses per person times 2(weekend) plus 60 PAOT times 3 uses per person times 5(weekday) times 50% equals 810 uses per week, or 3240 uses per month. Multiply by three to get manufacturers use number = 9720 uses per month times 3 months = 29,160 total adjusted expected use per year (this is conservative and depends on the manufacturers basis for "use").

Check a digester that can handle 65,000 uses per year at 18.3°C. (65°F.) or 5400 uses per month:

Adjust the recommended use for temperature at the following locations: (Average site temperature taken from US Atlas and is in Fahrenheit)
Location #1: Reno, Nevada

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Ave. Temp.	30	30	35	45	50	60	65	65	60	55	35	30
Adj. Use	0	0	0	1350	2025	4050	5400	5400	4050	2700	0	0

Total adjusted use = 24,975
Total expected use = 29,160

This unit could need added heat to decompose the expected volume.

Location #2: Albuquerque, NM:

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Ave. Temp.	35	35	40	50	60	70	75	75	70	55	45	35
Adj. Use	0	0	0	2025	4050	8100	10,800	10,800	8100	2700	1350	0

Total adjusted use = 47,925
Total expected use = 29,160

A smaller digester could be used at this site.

The above comparison demonstrates the need to adjust the manufacturers listed capacity to the type of recreational area and local climate. These calculations do not take into account sun exposure, elevation, or humidity. Manufacturers should be required to submit the site specific capacity calculations for their products prior to awarding a contract. The calculations submitted should include adjustments for temperature, humidity, sun exposure, and type of site. Due to the number of undersized digesters seen during the field review, a conservative approach seems justified.

1.Reed, S.C., Crites, R.W., Middlebrooks, E.J., "Natural Systems for Waste Management and Treatment", Second Edition, McGraw-Hill, New York, (1995)

2. Safton, Sandie-Lee, BSc, "Human Intestinal Parasites in Composting Toilet Systems", Dissertation available from Charles Sturt University, (1993)

3. U.S. Environmental Protection Agency, "Field Investigation of Biological Toilet Systems and Grey Water Treatment", (September, 1986)

4. Kreissl, J.F. "North American and European Experience with Biological Toilets", published in *Water Science Technology* (1986)

5. Smith, Michael E. "Evaluation of Compost Toilets", USDA Forest Service Equipment Development Center, San Dimas, CA (March 1981)

6. Cook, Briar "Field Evaluation of Compost Toilets", Published in *Individual Onsite Wastewater Systems,* NSF Seventh National Conference (1980)

7. Molland, Pederson, and Guttorsem, "Biological Toilets - A Solution to Pollution Problems" Presented at The United Nations Commission for Human Settlement, 6th Session, (1983)

8. Cook, Briar "In-Depth Design and Maintenance Manual for Vault Toilets, July 1991.

9. Technical Bulletin #1, "Composting Privy", The Farallones Institute.

•U.S. GOVERNMENT PRINTING OFFICE 1995-0-683-100/23009